Assessment of water resources in Yarmouk River Basin using geospatial technique during the period 1980–2020

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Abstract: It is common knowledge that Yarmouk River Basin (YRB) is shared between Jordan and Syria. Management of YRB trans-boundary water resources is attracting increasing interest because it is a strategic water resource for the riparian countries. Actually, lack of sharing information regarding hydrological flows and basin's water management between partners' countries makes it difficult to distinguish between natural and man-made factors affecting the water body. Therefore, this study seeks to address and assess the main on-site changes that exert on YRB. Geospatial technique and arithmetic equations were combined to carry out an assessment of the changes on water resources in YRB. Data, information and field measurements of the basin were aggregated, compiled and presented to determine the extent of changes during the period 1980–2020. Remarkable findings showed that precipitation amount in the basin significantly declined during the period 1980–2020 in particularly after the year 1992. Pumping rate of groundwater was 550×10^3 m^3/a, exceeding the basin's safe yield. Draw down of static groundwater level over time approached the value of –3.2 m/a due to the over abstraction in the aquifer body. Additionally, the evaporation rate reached more than 99% in some regions in the basin. Moreover, the number of private wells has increased from 98 wells in 1980 to 126 wells in 2020, showing the excessive extraction of groundwater. These findings indicate that the study area is subjected to a considerable groundwater depletion in the near future due to extensive abstraction, continuous drilling of illegal wells and decreased annual precipitation under the shadow of the rapid population growth and continuous influx of refugees. Therefore, decision makers-informed scenarios are suggested in the development of water resource portfolios, which involves the combination of management and infrastructural actions that enhance the water productivity of the basin. Further studies are recommended to evaluate the on-site changes on water resources in YRB in collaboration with riparian countries and to establish monitoring system for continuous and accurate measurements of the basin.

Keywords: assessment; geospatial technique; on-site changes; water resources; Yarmouk River Basin

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1 Introduction

Jordan is a country with very scarce water resources and is ranked the second most water-deprived country in the world. The supplied and consumed water amount of per capita per day was 126 and 71 L, respectively (Ministry of Water and Irrigation (MWI), 2016a). Currently, the

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rate of population growth in Jordan is 1.94% that is comparatively considered high (Awawdeh et al., 2019). This situation was aggravated by the huge refugee influx in the last decade. Consumption of groundwater is beyond the replenishment by more than 60% and 6 out of 12 major groundwater basins are over extracted (MWI, 2019). Furthermore, climate change forecasts proposed a significant decrease in current and future precipitation, which will aggravate water shortage especially in arid regions (Duan et al., 2021). Thus, renewable water resources are expected to decline in the future. As for water balance, Jordan only had 992×10^6 m^3 of total water resources available, while total water demand was 1401×10^6 m^3 (MWI, 2016a).

Yarmouk River Basin (YRB) is shared between Jordan and Syria. Upstream diversion and the construction of Syrian dams since 1968 in the upper reaches of YRB have reduced the flow of the river available to Jordan by 85%. Moreover, groundwater over abstraction in the Syrian part of the basin also explains much of the changes in the streamflow (Avisse et al., 2020).

The strategic importance of YRB is attributed to the fact that it is one of the major sources of groundwater and surface runoff in Jordan and the main sources of water for the King Abdullah Canal. Thus, YRB is considered to be the backbone of development in the valley of Jordan. The study area was important for the following reasons: (1) it is a typical agricultural watershed in Jordan; (2) there are intensive human activities that were identified as the primary contributors of sedimentation within the basin; and (3) it has been selected by the government to improve the upland conservation practices for reducing sedimentation.

According to Jordan's water strategy for the years 2016–2025, the deficit in the available water resources from YRB was approximately 41% in 2016 (MWI, 2016b). However, water deficit amount in 2019 was 10×10^6 m^3, given the safe yield of 40×10^6 m^3 and total water abstraction of 50×10^6 m^3 (MWI, 2019), which represents one of the highest relative deficits in comparison with other basins. The depletion of flows of major springs feeding Yarmouk River and the abstraction from wells for irrigation purposes will end up the long term reduction in the baseflow of the river and consequently water table dropping of shallow aquifers will occur (Salameh, 2004; Obeidat et al., 2019).

Salameh (2004) revealed that Jordan water supply from Yarmouk River is at high risk due partially to climatic change and notwithstanding expanded utilization. Bunning et al. (2016) discussed water assessment method in dry lands and identified that the extent and performance of water resources management alongside analyzing impacts of drought or over exploitation on water resources are of concern. Moreover, previous study explained what is called on-site changes on water resources, which are considered by the spatial location, effectiveness on water resources and fate to water resources in the study area. Analyzing these changes and updating relevant information are of high importance to determine the actual status and trends of water resources in a certain basin in terms of water quantity and hydrological regime (Duan et al., 2020; Meran et al., 2020).

The aim of present study is to analyze the main on-site changes that exert on YRB during the period 1980–2020 through assessing the surface water hydrology, evaluating groundwater resources and suggesting scenarios of water management. Geospatial technique and arithmetic equations were combined to carry out such assessment. Data, information and field measurements of the basin were collected, compiled and presented to determine the extent of changes during the aforementioned period. On the basis of anticipated findings of this study, different scenarios may be concluded and discussed with the decision makers to diminish the impacts on water resources and reduce risks. This study will allow for addressing spatial system-wide changes of different aspects of water resources assessment in the basin.

2 Materials and methods

2.1 Study area

YRB in the northern part of Jordan (Fig. 1) is a trans-boundary basin shared between Jordan and Syria. Yarmouk River originates on the southeastern downhills of Mount Hermon in Syria. The

main conduit of Yarmouk River forms the boundary between Syria and Jordan for 40 km, while its southern part forms partially the border between Jordan and Palestine. The central and southeastern parts of YRB are described as a smoothly contoured semi-desert land and the land falls towards the Jordan Rift Valley forming inclined cliffs and gorges (Obeidat et al., 2019). The elevation difference ranges from 1200 m at the highest ridges closest to Ajloun (Ras Munif) to –200 m near Adasiya in the Jordan Rift Valley.

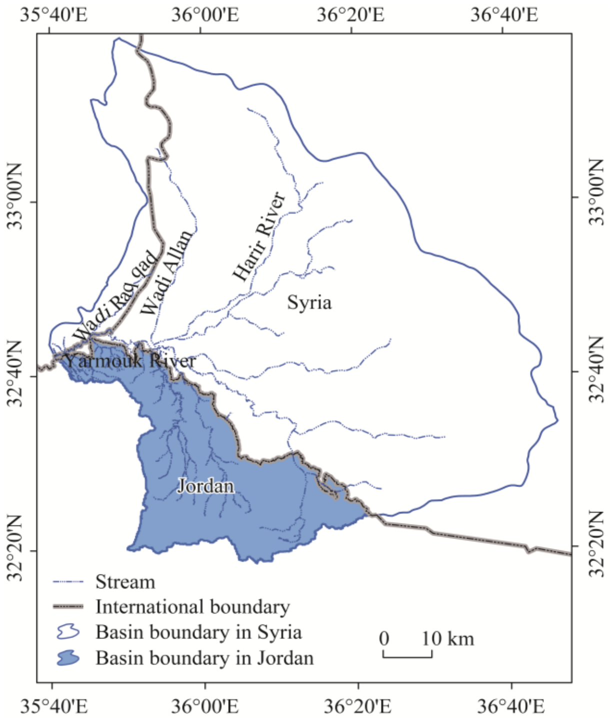

Fig. 1 Yarmouk River Basin (YRB) and its location with respect to Jordan

The average flow of Yarmouk River was 495×10^6 m^3/a in the 1950s (Hoff et al., 2011) and has been decreasing since then to reach a value of 83×10^6–99×10^6 m^3/a presently (Abdulla and Al-Shurafat, 2020). The total catchment area of the river was 6780 km^2; majority of it lies in Syria and Yarmouk River in Jordan, while the rest of area of approximately 1160 km^2 lies in the upstream of Yarmouk River in Jordan. The area is mostly agrarian land, with some small industrial zones. During floods, small amounts of wastewater runoff reach the river. Yarmouk River has permanent baseflow as well as considerable flood flows. Its flows originate from Syrian territory, while smaller amount of flows comes from Jordanian land. The flows of Yarmouk River are derived from precipitation in winter season and supplemented by spring discharges in the basin that has a semi-arid Mediterranean climate in the west and an arid climate in the east. The precipitation gradient is obvious across the westeastern direction, where the mean annual precipitation ranges from 500 mm in the west (Samar weather station) to 133 mm in the east (Hosha weather station). The minimum mean temperatures is 12.3℃ in the lowlands (Jordan Rift Valley) and the maximum is 23.1℃ in the highlands, respectively (MWI, 2016c; Obeidat et al., 2019). It is a typical case to construct dams as an adaptation approach increases water supply for mitigating anticipated water shortage. Therefore, Al-Wehada Dam was constructed on Yarmouk River in the border area of Jordan and Syria for drinking and irrigation purposes in 2004. However, water from the dam is used for irrigation due to considerations of water quality and quantity as it collects winter floodwater from YRB and springs.

2.2 Data collection

The hydrogeological and meteorological data were obtained from the Ministry of Water and

Irrigation (MWI) and Jordan Meteorological Department (JMD), such as but not limited to geologic information, hydro geological data, groundwater and surface water data and climatic data (daily temperature, relative humidity, hourly sunshine, wind velocity and direction, monthly average precipitation and potential evaporation). The data and measurements collected are mostly associated with locations. Data were represented as discrete values, stored by its exact geographic location as vector data.

Additionally, the digital elevation model (DEM) of the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) with a 30 m×30 m resolution was obtained from US geological survey website (US Geological Survey, 2021). This study focused on achieving water resources appraisal through analyzing different changes on groundwater and surface water resources that affect the hydrological regime in the basin. The manual given by Bunning et al. (2016) has explained significant changes on water resources. Accordingly, in the present study, we identified the most prominent on-site changes in the study area according to its potential, which include change in surface water availability (streamflow amount including mainly the base flow and flood flow), change in groundwater availability (abstraction, monitoring wells and depth to water table) and expansion in water extraction from growing numbers of private or unlawful wells. Subsequently, the aforementioned changes were processed through a developed quantitative water resources assessment approach as discussed in the next section of data processing.

2.3 Data processing

The raw data representing the changes were analyzed, processed and validated to get the expected results that were achieved through applying a developed approach as demonstrated in Figure 2. Data obtained were processed using different methods. The collected data of abstraction and monitoring wells, boundary of YRB, climatic and streamflow parameters were prepared and processed using ArcGIS v10.7.1 software to produce exemplified maps, while the collected data of precipitation, evaporation and climatic parameters were handled by mathematical equations to compute values of evaporation rate and mean areal precipitation for the whole surface of YRB. These data were interpolated using ArcGIS v10.7.1 software. The data layers were graphically combined using analytical operators (overlay analysis). Afterwards, the graphical layers were processed into diagrammatic representations as maps in order to attain sound interventions of water resources management in the basin.

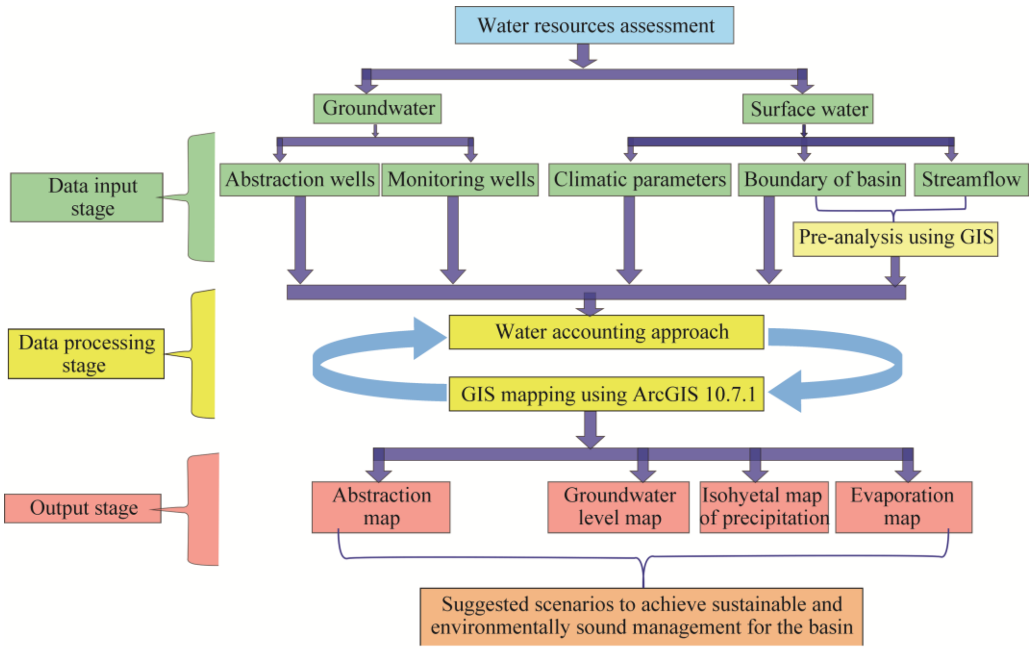

Fig. 2 Schematic diagram of the developed water assessment approach applied in the study

The sub-basins of YRB were delineated using Geographic Information Systems (GIS; Fig. 3). Moreover, a DEM was used to compute the flow direction and drainage network. The precipitation and evaporation data were interpolated using the Inverse Distance Weighted (IDW) method. For precipitation calculations, the Thiessen polygons (areal precipitation) method was chosen to compute the mean areal precipitation for each sub-basin based on rain gauging stations

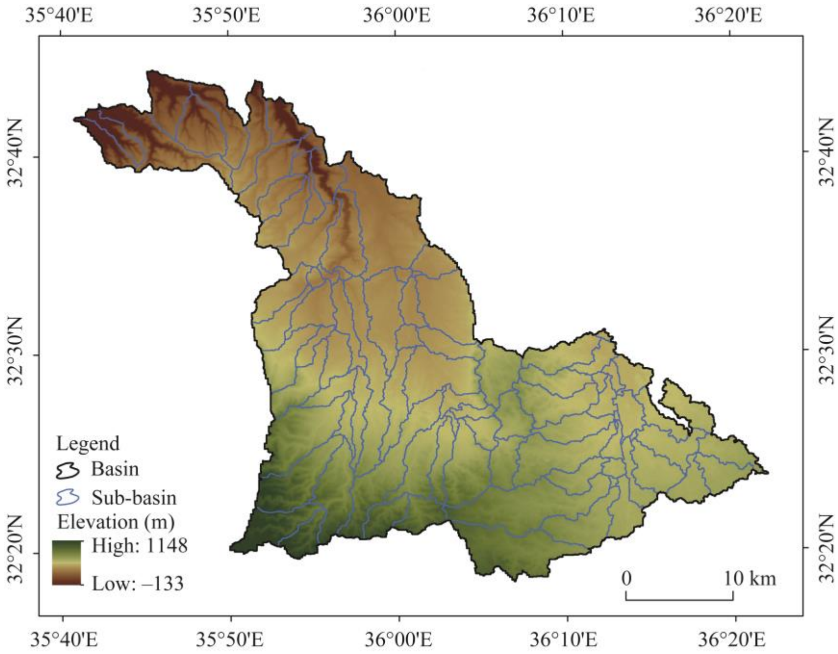

Fig. 3 YRB watershed and its sub-basins

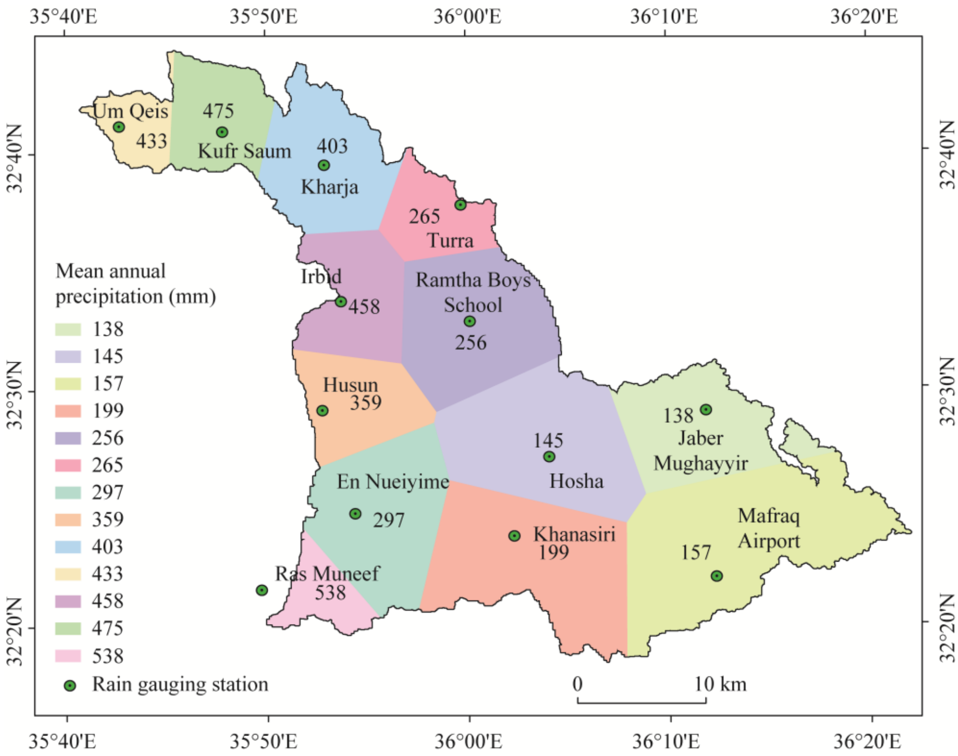

Fig. 4 Distribution of mean annual precipitation using the Thiessen Polygons method

observations. The calculations were based on the precipitation data from 13 stations during the period 1980–2020 (Fig. 4 and Table 1). Each station has an influence area that can be determined after the construction of the polygons. Value of precipitation measured by a rain gauging station is assigned to the area multiplying the precipitation by its representative area, as shown in the following equation:

$$P = \frac{1}{A}\left(\sum A_i \times P_i\right), \tag{1}$$

where P is the total precipitation in the basin (mm); A is the total area of the basin (km^2); A_i is the Thiessen polygon area (km^2); and P_i is the amount of precipitation over each Thiessen polygon (mm). Moreover, point data from stations surrounding the study area were interpolated to a raster

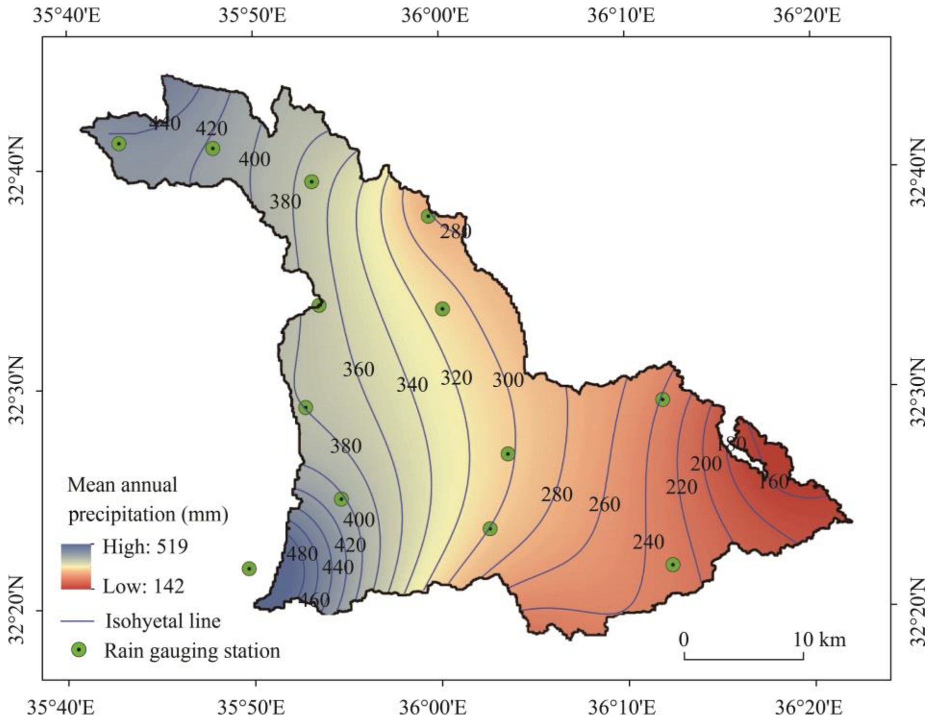

Fig. 5 Isohyetal map of spatial distribution of mean annual precipitation in YRB

Table 1 Mean annual precipitation of Jordanian side of Yarmouk River Basin (YRB) and area covered

Station	Area covered (km^2)	Percentage of total area (%)	Mean annual precipitation (mm)
Khanasiri	151.0	10.6	199
Mafraq Airport	148.0	10.4	157
Hosha	155.0	10.9	145
Jaber Mughayyir	163.0	11.4	138
Kufr Saum	107.0	7.5	475
Um Qeis	49.6	3.5	433
Kharja	119.0	8.3	403
Husun	87.0	6.1	359
En Nueiyime	139.0	9.7	297
Ramtha Boys School	134.0	9.4	256
Turra	74.2	5.2	265
Irbid	44.9	3.1	458
Ras Muneef	54.6	3.8	538

surface using the surface interpolation method IDW. Subsequently, the interpolated surface was used to derive the contour map of mean annual precipitation of YRB (ESRI, 2021).

Furthermore, 6 climatic stations (Table 2) located in YRB were considered for analysis. Each of these stations contributes to measure the daily temperature, relative humidity, hourly sunshine, wind velocity and direction, monthly average precipitation and potential evaporation. Among these parameters, the daily temperature and monthly average precipitation measurements were validated during the period 1980–2020 for the purpose of evaporation calculations in the study. The preliminary estimation of evaporation in this study was calculated using Turc formula (Eq. 2) (Turc, 1951). Turc formula is one of the methods used for evaporation calculation in Mediterranean climatic conditions with limited climatic data and it is mainly used for the large area (Adamovoic et al., 2015). This equation is written as follows:

$$E = P / \sqrt{0.9 + (P^2 / f(t)^2)}, \tag{2}$$

where E is the actual evaporation (mm); P is the mean annual precipitation (mm); and $f(t)^2$ is the capacity of the atmosphere to evaporate water that is expressed by the following equation:

$$f(t)^2 = 300 + 25T + 0.05(T)^3, \tag{3}$$

where T is the annual mean temperature (℃). The mean temperature that was used in the Turc formula was taken for the wet months between October and May. The evaporation for the whole

Table 2 Calculated long-term evaporation rates for the climatic stations in YRB

Station code	Climate station	Total area (%)	Area covered (km^2)	Evaporation rate (%)
AE0002	Irbid	15.1	215	97
AH0003	Ras Muneef	9.7	139	92
AD0032	Baqura	1.1	15	95
AD0019	Mafraq Airport	26.2	374	100
AD0004	Samar	15.3	218	96
AD0012	Ramtha	32.6	465	99

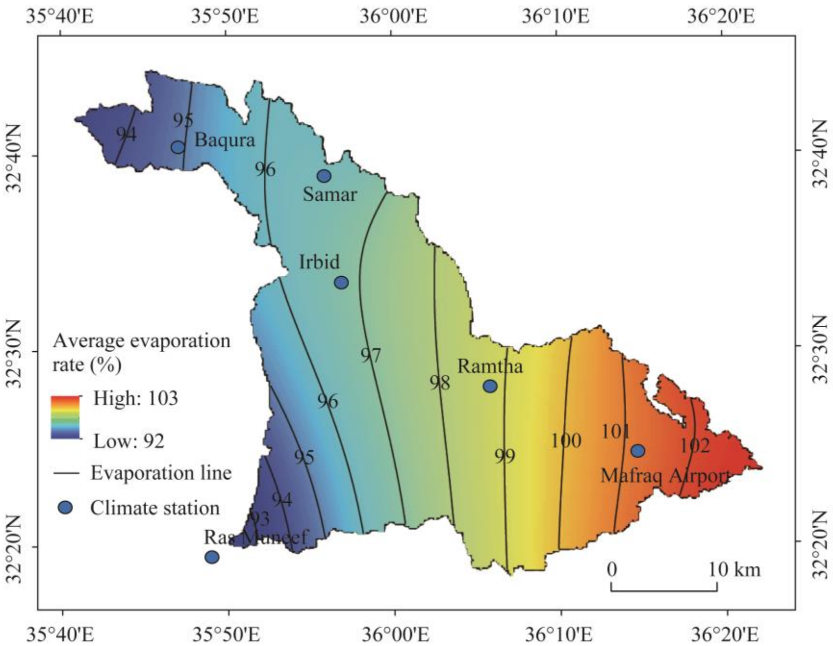

Fig. 6 Average evaporation rate of YRB

record period (1980–2020) for the basic climate stations was calculated.

Moreover, the abstraction wells locations were identified. The abstraction amount from these wells were measured monthly by the MWI. Abstraction value varied as per the yield of wells and reservoir storage capacity. On the other hand, monitoring wells are used only to measure static water level by taking value of water depth from the top of wells. The measurements data were on monthly basis and kept in Water Information System (WIS) as oracle database. The data were imported to ArcGIS for validation and analysis. Furthermore, streamflow data represent the wastewater treatment plants effluent, springs, flood flow, baseflow and the amount of water stored in the Wehdah Dam. These data were taken by the MWI during the period 1980–2020, as the amount of flow passing points is measured as charts using the installed gauging stations then stored in the WIS to extract values. The values of annual streamflow of two representative streamflow gauging stations were calculated and displayed in charts.

2.4 Building up thematic maps and recommending management scenarios for addressing the changes on water resources in YRB

The hydrogeological and climatic data were processed to produce exemplified maps or to compute values of climatic parameters as discrete values that were delineated afterwards as maps as well. Thematic maps were generated as visual representations of the on-site changes to assess the current situation of water resources in YRB. These maps help the researcher to answer different questions concerning on-site changes studied. This enables decision makers to improve the effectiveness of water resources management and anticipated water conservation projects.

3 Results and discussion

Many significant changes were analyzed either visually through geospatial mapping technique using GIS or arithmetically. The footprint of these changes on water resources in the study area is presented and discussed in the following sub-sections.

3.1 Watershed delineation

YRB consists of several sub-basins as shown in Figure 3. A DEM layer was integrated using GIS. Subsequently, the existing sub-basins were delineated in the study area as well as new hydro logical features were delineated. Furthermore, the flow direction is obvious from southwestern highlands of 1148 a.s.l. toward the northwestern plains of –133 a.s.l. extending through Jordanian border toward Syria.

3.2 Precipitation

The spatial distribution of mean annual precipitation over YRB was carried out using the Thiessen Polygons technique during the record period as shown in Figure 4. The highest monthly precipitation was recorded by Ras Muneef station and the minimum monthly value was recorded by Jaber Mughayyir station. While En Nueiyime and Turra stations represented the average values of the basin. Table 1 describes the mean annual precipitation of these stations from 1980 to 2020 in Jordanian side of YRB using the Thiessen Polygons method. The hydrological year in Jordan is divided into a rainy season from October to May and a dry season for the rest of the year. The mean annual precipitation is shown in the isohyetal map in Figure 5. Precipitation decreases dramatically from 520 mm in the southwestern highlands at Ras Muneef station to less than 150 mm in the eastern plateau of Mafraq Airport station, which dovetails the effect of rain shadow of the western highlands. Using the Thiessen Polygons method, we estimated the weighted mean precipitation for YRB as 277 mm during the period 1980–2020. This is similar to the prevalent semi-arid Mediterranean conditions with the highly variable climate in Jordan (Obeidat et al., 2020). Moreover, since precipitation is one of the main climatic factors affecting water resources of a watershed (Duan et al., 2020), it's crucial to develop practices to manage scarce water resources, and increase water use efficiencies in order to conserve and sustain the already fragile water resources.

3.3 Evaporation

Evaporation for the climate stations was calculated and the results for which are summarized in Table 2. The calculated long-term evaporation rates ranged from 92% at Ras Muneef station to approximately 100% at Mafraq Airport station and the surrounding regions. The spatial distribution of the long-term evaporation rate shown in Figure 6 increases dramatically when shifting from west to east of the basin, which reflects the variation in climate patterns effect from semi-arid to arid in this direction of YRB.

3.4 Streamflow

The majority of the basin's water come from streams, including those that do not flow all the time such as spring-fed ponds or ground depressions that fill up with water after every rain event. The runoff in Yarmouk River consists of two main parts. Direct runoff from precipitation (flood flow) to drainage channels, which is extremely variable and is effective from October to May. Base flow originates from groundwater and flows in wadis throughout the year (perennial flow), which is available without storage. Baseflow in semi-arid regions is considered to be the component of the total streamflow predominantly due to groundwater discharge into a river under low flow conditions over dry season as the case in YRB (Courcier et al., 2005). There are two main streamflow gauging stations (Maqaren and Adasiya) that exist in YRB in the Jordanian side since the late 1960s. Maqaren station is situated at 32°44′N and 35°51′E with an elevation of 12 m a.s.l. A streamflow records at Maqaren station cover Al Wehdah catchment. Adasiya station is located at 32°41′N and 35°37′E with an elevation of –210 m a.s.l. It represents the outlet of the entire YRB, where both Jordanian and Syrian parts of YRB drain to this point. The majority of baseflow or groundwater contribution to Yarmouk River recorded at Maqaren and Adasiya gauging stations flows from the aquifers and springs from the Syrian side of YRB. Figures 7 and 8 show the annual streamflow at Maqaren and Adasiya stations during the period 1980–2020.

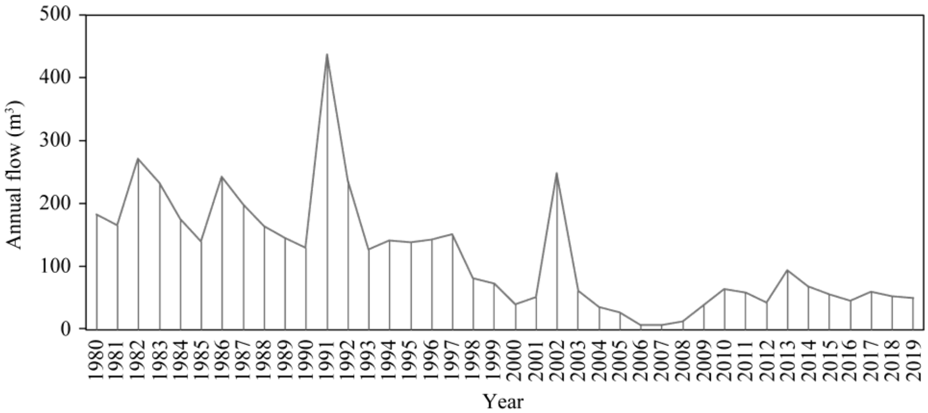

Fig. 7 Annual streamflow of Maqaren gauging station in YRB

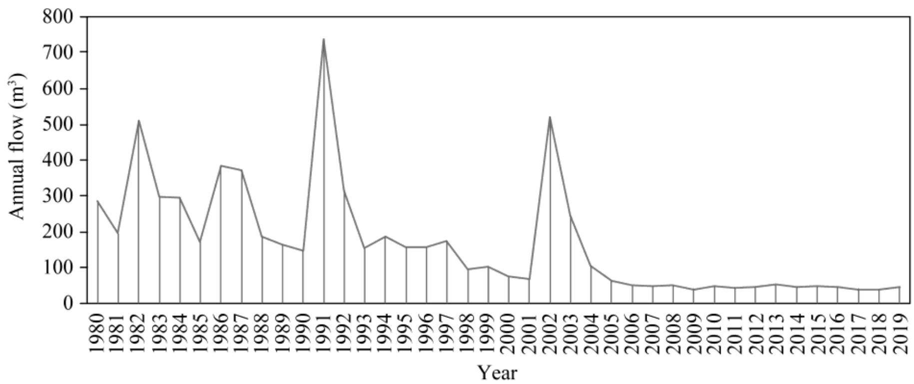

Fig. 8 Annual streamflow of Adasiya gauging station in YRB

It is clear that there is a declining trend in the streamflow since 1992. This can be interpreted as one of the warming signs that can significantly influence rainfall patterns and can dramatically impact runoffs and groundwater recharge. These findings appear to be in line with Kunstman et al. (2007) findings.

It is worthwhile noting that there are two other streamflow gauging stations (Shallala and Esh Shaumar) in YRB as secondary stations in addition to the two main gauging stations (Maqaren and Adasiya). However, they were not considered in the study because they have only sporadic datasets as the data are not available for 30 a during the period (1990–2020) for Shallala station and for 25 a during the period (1995–2020) for Esh Shaumar station. This might be considered as a source of uncertainty. Despite this, we can still state that the two main gauging stations can cover streamflow measurement at the outlet of the main tributaries of Yarmouk River.

3.5 Abstraction

Despite of water scarcity in Jordan (Awawdeh et al., 2020; UNICEF Jordan, 2021), the level of water supply in the basin is fairly high, since it covers almost 94% of the population (MWI, 2016). However, the distribution system performance is still below optimal level and efficiencies are still low. Households in YRB receive water once a week for a limited number of hours and use roof-top tanks to store their weekly water needs. The intermittent supply regime also creates additional risks such as water quality deterioration during storage. The total amount of groundwater delivered to YRB for domestic purposes is around 59×10^6 m^3. Noting that the total domestic uses of the basin's water is 12×10^6 m^3 does not fulfill the locals' needs, the difference is complemented from other basins. Plainly, groundwater pumping from the basin of 50×10^6 m^3 surpasses the safe yield by 10×10^6 m^3 as water deficit (MWI, 2019). Within the basin boundary, there are about 69 state-owned wells to cover the domestic purposes and 126 private wells out of which 11 illegal wells are used for agricultural purposes, while there were only 98 wells in the 1980s (WAJ, 2019). The abstraction rates from pumping wells are shown in Figure 9. The size of symbol indicates quantity of water abstracted per year. The pumping rates for these wells range from 550×10^3–300×10^3, 300×10^3–200×10^3, 200×10^3–150×10^3, 150×10^3–75×10^3 to 75×10^3–2×10^3 m^3/a as shown in

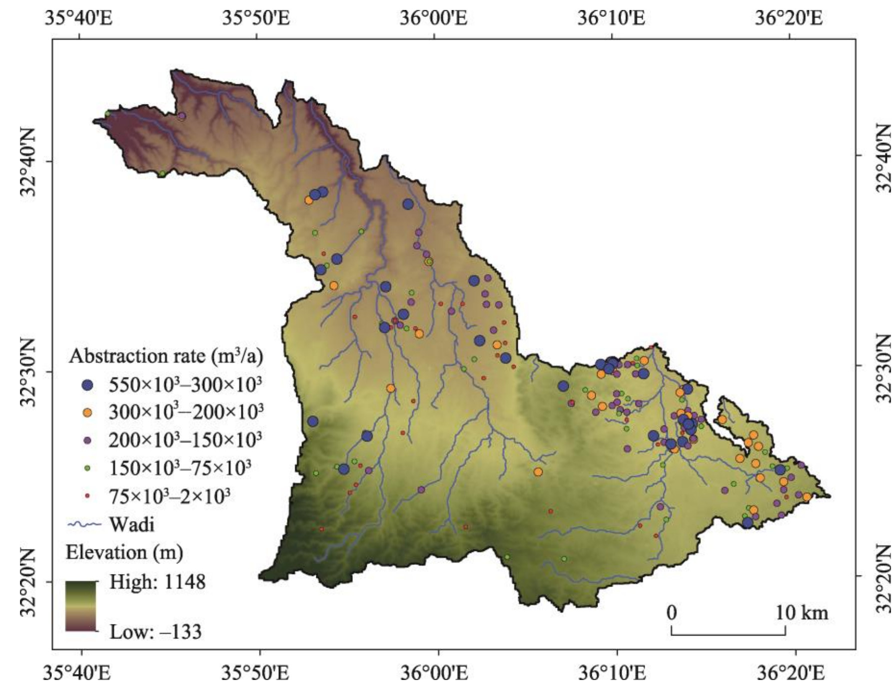

Fig. 9 Abstraction rate from pumping wells of YRB

Figure 9 in 2019. The number of state-owned and private wells for each class are 33 and 12, 4 and 25, 6 and 33, 8 and 29, and 10 and 26, respectively. In this way, total amount of water abstraction reached 50×10^6 m^3 in order to cover the local demand exceeding the basin's safe yield 40×10^6 m^3.

3.6 Groundwater monitoring

A number of monitoring wells are used to assess the impact of abstraction on groundwater levels. Most of monitoring wells are equipped with automatic recorders. The drawdown rate of groundwater level during the period 1980–2020 is shown in Figure 10. It is observed that the drawdown rate varies from –3.2 to –0.9 m/a. This could be attributed to different factors including low amount of precipitation, over abstraction in the aquifer body, increased number of private wells, drastic population growth and sudden influx of refugees. However, lack of sharing hydrological information between partners' countries makes it difficult to distinguish between natural and man-made factors affecting the water body.

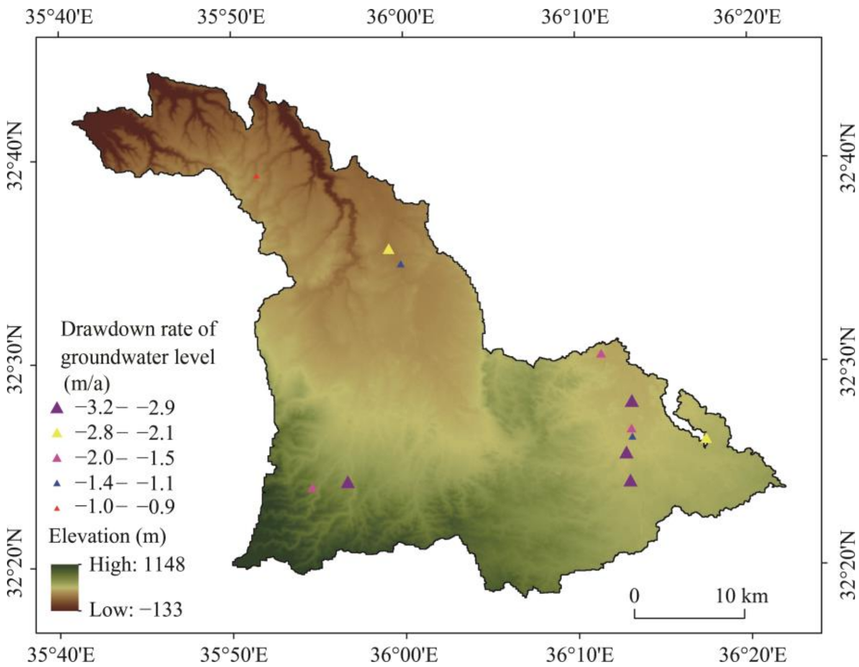

Fig. 10 Drawdown rate of groundwater level from monitoring wells in YRB

3.7 On-site changes on water resources in YRB

This study sheds light on newly integrated approach of the so-called "on-site changes on water resources" that can cause degradation of water resources. We selected changes studied based on hydrological properties and its water resources in the study area. Accordingly, various parameters discussed in the study showed significant changes on water resources. These changes are illustrated either visually by mapping or arithmetically. The imposed changes of different parameters are interpreted in details as the extent of each impact is summarized in Table 3.

It is plausible that a limitation may have influenced the results obtained regarding the period length of used data from 1980 to 2020 to assess the change in water resources of YRB. Further data for a longer period may provide more accurate and reliable assessment results.

4 Conclusions and recommendation

On-site changes on water resources in YRB during the period 1980–2020 can be summarized as follows: precipitation amount significantly declined since 1992, subsequently, annual streamflow showed a decline trend. Pumping rate of groundwater surpassed the safe yield. This situation was

Table 3 Extent of imposed on-site changes on water resources in YRB

On-site change	Extent of change
Change in surface water availability (streamflow amount including baseflow and flood flow) using data of relevant gauging stations	During the period 1980–2020, the highest mean annual precipitation occurred at the southwestern boundary of the basin (520 mm) and the lowest at the east of the basin (142 mm) due to the weather system interventions at various basin's relief. However, using the weighing average method, the weighted mean precipitation for the entire basin is 277 mm that dovetails the semi-arid Mediterranean climate to arid climate in YRB. The values of annual streamflow in YRB clearly show an obvious declining trend especially after 1992 (440×10^6 m^3) in comparison with 2020 (50×10^6 m^3) in Maqaren gauging station as an example, which assures the influence of warming on precipitation and can dramatically impact runoff and groundwater recharge.
Change in evaporation rate from bare ground and open watershed	The calculated long-term evaporation rates for the climate stations ranged from 92% to 100% at the southwestern highlands and eastern regions of the basin, respectively. It is obvious that this influence dramatically increases when shifting from west to east, reflecting the effect of climatic patterns from semi-arid to arid regions in YRB.
Change in groundwater availability (abstraction, monitoring wells and depth to water table)	Ranges of pumping rates with a maximum of 550×10^3–300×10^3 m^3/a are relatively high values that cause the excess of the basin's safe yield. Drawdown rate of groundwater level over time due to over abstraction in the aquifer body varies from –3.2 to –0.9 m/a due to low amount of precipitation, natural and sudden increase in the number of population in addition to requirements of agribusiness interventions.
Expansion in water extraction from growing numbers of private or unlawful wells	Number of state-owned and private wells are 33 and 12, 4 and 25, 6 and 33, 8 and 29, and 10 and 26, respectively, for the pumping rates with the ranges from 550×10^3–300×10^3, 300×10^3–200×10^3, 200×10^3–150×10^3, 150×10^3–75×10^3 to 75×10^3–2×10^3 m^3/a, respectively.

aggravated by the climatic conditions leading to a high evaporation rate in addition to the rapid population growth and influx of refugees. Decision makers and other concerned parties are encouraged to set a more stringent strategy to comply with the extensive abstraction. A legislative framework is suggested to handle the problem of illegal wells. More attention should be paid to water saving awareness from public and farmers. Additionally, further studies are recommended to establish full monitoring system to provide continuous and accurate measurements for more effective basin management and to carry out evaluation of on-site changes on water resources in YRB in collaboration with riparian countries.

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